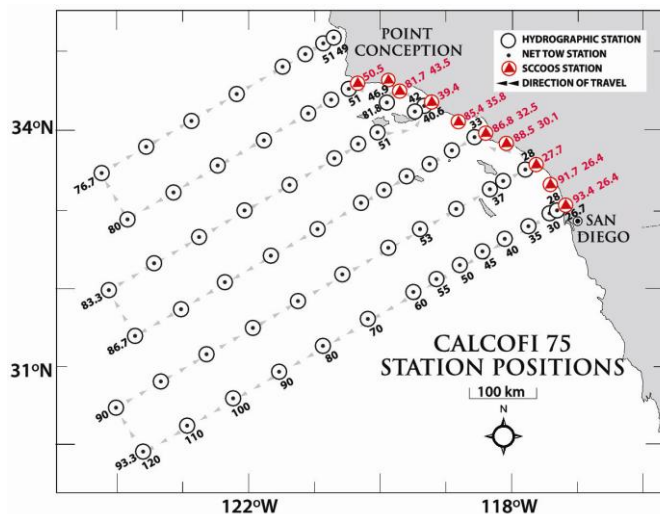


California Cooperative Oceanic Fisheries Investigations (CalCOFI) Research Plan

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- Larval abundance time series to be used in data-poor assessments for northern anchovy, jack mackerel, and sanddabs.

Theme 2. Ecosystem analysis: Assess and predict how environmental changes and human activities affect ecosystems and design and implement new management paradigms to manage fisheries and recover protected species.

CalCOFI provides:

- The long-time series for a wide range of biological, physical and chemical variables off southern California.
- The baseline against which anomalies, or deviations from average conditions, can be calculated to determine how inter-annual variability compares against other years.
- The basis to calculate secular or long-term trends in both physical and biological variables which reflect change in the ecosystem.
- Larval time series that can be used to measure the effect of establishing conservation areas off southern California.

Theme 3. Observations, measurements and surveys: Provide information and data to support population assessments and analyses of ecosystem variability and change.

The SWFSC and SIO CalCOFI teams provide:

- The expertise and logistical capability to maintain a quality controlled and consistent monitoring of the southern California Current ecosystem on a quarterly basis, ranging from the coastal waters, across the continental shelf and into oceanic waters out to more than 530 km offshore.
- Reliable and standardized measurements of hydrographic profiles and discrete depth samples, ichthyoplankton and zooplankton abundances from nets, primary productivity rate measurements, phytoplankton size fractionations, Particulate Organic Carbon/Dissolved Organic Carbon, Dissolved Inorganic Carbon, multifrequency acoustic backscatter from fish and krill, as well as marine mammal and seabird abundances.
- Expert taxonomic identification and standardized abundance of over 400 species of ichthyoplankton (fish larvae, and selected eggs) and cephalopods.
- Data are provided on the Internet to the public as maps, specific data sets, and extensive data tables for the entire CalCOFI time series.

Theme 4: Technological innovation and development: Improve ecosystem observations and survey methodologies through a variety of advanced technologies and sensor development.

CalCOFI staff provide:

- An extensive reference collection of ichthyoplankton used by taxonomists worldwide to improve and calibrate identifications in other collections.
- A long time series of ethanol preserved plankton samples suitable for genetic research.
- New genetic methods for identification of larvae of many rockfish species, as well as other fish taxa, fish eggs, and cephalopod paralarvae that cannot be identified from morphology.
- New isotopic techniques to evaluate whether larval diets affect recruitment success.

Goals of CalCOFI

Background

The CalCOFI program was an outgrowth of field studies in the 1920s, 1930s and 1940s conducted as collaborations between California Department of Fish and Game, Scripps Institution of Oceanography, the California Academy of Sciences, and the U.S. Bureau of Commercial Fisheries (Hewitt 1988). The initial rationale for the CalCOFI survey program was to determine why the Pacific sardine (*Sardinops sagax*) fishery drastically declined in the 1930s and 1940s, by studying the pelagic environment and the fishery.

CalCOFI developed in the context of competing hypotheses to explain the observed fluctuations in fish stocks. The two main hypotheses were that fluctuations, and in particular collapses, in small pelagic fish stocks were primarily driven by the environment or, alternatively, were mainly controlled by fishing pressure. Initially the causes of the sardine decline were thought to be related to environmental variability, but there was increasing realization, largely based on observations of the effects of bottom trawling on demersal fisheries elsewhere, that fishing pressure might also impact the sardine stock. A third more recent hypothesis affecting research direction in the CalCOFI program was that predation on ichthyoplankton and juvenile fish was an important determinant of recruitment success. Perhaps not surprisingly, the modern view partly integrates these opposing hypotheses, such that linear and non-linear interactions of components of all three of these hypothesized mechanisms can contribute to fluctuating biomass of small pelagic fish.

The context and rationale for the CalCOFI program has changed since the first 3-ship west coast-wide cruises in 1949 initiated under the California Cooperative Research Program (Hewitt 1988). After the first decade, the rationale of the CalCOFI program was already changing focus and broadening away from just sardine to try and understand fluctuations in other commercially important species, including northern anchovy (*Engraulis mordax*) (Hewitt 1988). The increasing abundance of anchovy in the 1960s became a focus for research as the anchovy replaced the sardine (Hewitt 1988).

A critical decision was made at the beginning of CalCOFI by Dr. Elbert Ahlstrom. While the initial goal of the program was a sardine survey, Ahlie, as he was known world-wide, insisted that all fish eggs and larvae should be sorted from the plankton tows, and that all species should be identified. It would be many years before that goal was achieved, but the fruits of that labor are borne today in time series of larval abundances for both exploited and unexploited species of fish. The *Ontogeny and Systematics of Fishes* (Moser et al. 1984), dedicated to Ahlie and published by the American Society of Ichthyologists and Herpetologists, is a tribute to his foresight and contributions.

The larger vision of an ecosystem approach was fundamental to the CalCOFI program from the outset. The scale of the CalCOFI program in terms of area covered, intensity of sampling and the range of measurements taken was unprecedented. More conventional harvest yield studies continued at the California state fisheries agencies, but these also received extra funding to broaden the basic science studies undertaken (Scheiber 1990). From the outset the CalCOFI program focused on the dynamics of change in the ecosystem. The long-term database provided by the CalCOFI program now provides a unique resource for the study of climate change. Within about a dozen years of its inception, there was no other area of the world's ocean, except perhaps the seas of Norway, that was as well studied as the California Current System (Scheiber 1990). The CalCOFI program is an example of Large Marine

Ecosystem Research initiated four decades before the concept became widely used. Even before the 1970s, research was conducted under CalCOFI that meets the scientific criteria for ecosystem science underpinning ecosystem management (Christensen 1996 cited in Scheiber 1990). These criteria include “a focus on sustainability and on the dynamic character of ecosystems, a recognition of the importance of appropriate spatial boundaries, and an awareness of uncertainty and adaptation” (Christensen 1996). CalCOFI research also gave attention to inter-species competition for food supply which is particularly relevant for multispecies management (Scheiber 1990).

Original goals of CalCOFI

The initial rationale for the CalCOFI survey program was to determine why the Pacific sardine fishery drastically declined in the 1930s and 1940s, by studying the pelagic environment and the fishery. Specifically, the program was charged with “investigating the sardine in relation to its physical and chemical environment, its food supply, its predators and its competitors, in attempting to evaluate the findings in terms of the survival of the young, and in terms of the current distribution and availability of the sardines when they reach commercial size.” (Hewitt 1988). It was hoped that an oceanographic approach would underpin better management of the fishery in the future (Hewitt 1988, Ohman & Venrick 2003, Scheiber 1990).

Current goals of CalCOFI

The goal of the modern CalCOFI program can be broadly expressed as the understanding of long-term changes in the California Current Ecosystem, or CCE (Ohman & Venrick 2003). This goal is recognized as being intimately linked with basin-scale processes, and CalCOFI has been embedded in larger scale studies of the Pacific since its early days (Brinton 1962, Chelton et al. 1982, Fager & McGowan 1963, McGowan 1985, Reid 1962).

CalCOFI Clients

CalCOFI provides products (data, syntheses, reference collections, and new methods) to diverse clients in the science and management communities. The science community served by CalCOFI includes the climate, fisheries, environmental, and taxonomy communities. The management community served by CalCOFI includes the Pacific Fisheries Management Council and the Marine Sanctuaries.

This research plan briefly outlines CalCOFI commitment to provide specific products to each of these communities, according to their needs, given our current resourcing.

CalCOFI Science clients

Climate

Significant knowledge gaps remain for all of the research priorities identified in the 2009 National Climate Assessment report, released by the U.S. Global Change Research Program (USGCRP) (Corell et al 2014). “These include **the need for a more comprehensive, interdisciplinary, use-inspired, and integrated research enterprise that combines fundamental understanding of climate change and response choices, that improves understanding of human-environment systems; that supports**

effective adaptation and mitigation responses, and **that provides better observing systems and projections.”**

CalCOFI provides an interdisciplinary ocean observing program, with a focus on fisheries oceanography, biological oceanography and climate change, that facilitates integration with regional modeling and forecasting systems. In the southern California region, CalCOFI is well placed to help address some of the knowledge gaps identified by Corell et al (2014).

Corell et al. (2014) summarize “the research needs and gaps that emerged during development of the Third National Climate Assessment report”. The first two needs are:

Improve understanding of the climate system and its drivers

by (1) Continuing efforts to improve the understanding, modeling, and projections of climate changes, (2) Improve characterization of important sources of uncertainty, including feedbacks and possible thresholds in the climate system, (3) Develop indicators that allow for timely reporting and enhanced public understanding of climate changes, and (4) Advance understanding of the interactions of climate change and natural variability at multiple time scales.

Improve understanding of climate impacts and vulnerability

by (1) Maintaining and enhancing research and development of data collection and analyses to monitor and attribute ongoing and emerging climate impacts across the United States, including changes in ecosystems, (2) Assessing the impacts of climatic extremes, high-end temperature scenarios, and abrupt climate change.

The CalCOFI program provides regional scale monitoring, data and syntheses that are directly relevant to these research needs. As the CalCOFI time series continues to grow in length, it becomes increasingly useful for characterizing natural variability and thresholds for change. There is a great deal of scope for developing new indicators. Timeliness is a challenge, but could readily be addressed by targeted increases of resources, by funding more laboratory technical staff. The CalCOFI program has run for sufficient time to permit investigations of climate related interactions at multidecadal, inter-annual and seasonal time scales. The core CalCOFI data collections and associated metadata, as well as sample archives, and reference collections are well maintained. Data are publicly served through the NOAA ERDDAP interface. These data facilitate the understanding of regional effects of climate extremes, such as the recent anomalous warm events, and permit the monitoring and detection of abrupt climate change events. The CalCOFI data are well integrated with regional modeling efforts using both Global Climate Models (GCM) and the Regional Ocean modeling System (ROMS), in terms of model calibration, data assimilation into models, hindcasting and reanalysis model products.

Fisheries

The management of living marine resources requires biological reference points and time series against which changes in such reference points can be measured (Busch et al. submitted). An implicit assumption is that recent variability will approximate historical variability. However, future conditions are forecast to move outside the envelope of historical variability of the last 50 years or more, and to detect such deviation it is necessary to use data like those from CalCOFI to permit the calculation of anomalies. CalCOFI can also aid in **“identifying appropriate, climate-informed reference points for**

managing living marine resources” (Busch et al submitted) that are **“robust to shifting status of managed species (Punt et al 2014) and ecosystem change”**.

In a changing environment, fisheries management strategies developed in the absence of environmental information may not be optimal (McClure et al. 2013). **“Climate-related information may need to be incorporated into the management process to effectively achieve management and conservation goals”** (Busch et al submitted). To date, environmental information incorporated in harvest control rules for US West coast fisheries have been very simple (Lindegren & Checkley 2013), but the CalCOFI data are well suited to develop more mechanistically based indices, which may or may not perform better. **“Successful climate and living marine resource management strategies should incorporate robust management strategies, allow for regular updates in the short term based on performance tracking, and periodically be evaluated against rigorous management strategy evaluations that employ fully coupled sets of system models. The ability to adapt on a routine basis without having to execute detailed analyses each year is necessary for success”** (Busch et al. submitted). The quarterly CalCOFI surveys are ideal for providing updates of environmental variables used in harvest control rules, and for facilitating the re-evaluation of environmental indices that should also be part of the process.

An important aspect of managing fisheries under climate change is the ability to track trends, and develop indices of change as well as early warning indicators of potential shifts in biological communities. Such shifts, sometimes referred to as regime shifts, are an important aspect of variability in the US west coast ecosystems, and may require significant adjustments in fisheries management. CalCOFI is well-placed to develop these sorts of indicators (Sheffer et al 2001, Dakos et al 2015) and currently funded collaborative projects including the CalCOFI data began in 2016 (Hunsicker et al 2016 FATE).

Environmental

CalCOFI data and synthesis products are used to address a wide range of environmental questions, and these will continue to evolve and proliferate overtime.

The science community with an interest in current conditions in the California Current Ecosystem uses the annual State of California Current paper published in CalCOFI Reports as a valuable review of environmental conditions. The California Current Integrated Ecosystem Assessment (CC IEA) draws on synthesized products produced by CalCOFI, or other groups such as staff in SWFSC ERD using CalCOFI data, to provide indices used in the report, and in IEA presentations to stakeholders. Environmental consulting companies monitoring sewage and powerplant outfalls use CalCOFI data to provide the context for their nearshore measurements. Industry funded researchers for the California Wetfish Producers Association use CalCOFI paralarval counts of market squid in their monitoring studies.

CalCOFI data are used by the science community to address many environmental questions. For example, among them are questions such as: (1) is it warmer than normal off southern California this year? (2) Is the 2016 El Nino comparable to the 1997/98 El Nino? (3) Is increasing hypoxia affecting our region (4) What are the spatial and temporal trends in acidification? (5) Are there any trends in non-commercial fish species, such as mesopelagic fishes, that we should be concerned about? In addition, we are fielding questions from SWFSC HMS scientists about whether CalCOFI data can help

to understand the movements of sharks and tunas, and we receive similar questions from SWFSC MMTD concerning the movements of turtles.

Taxonomy

The ichthyoplankton laboratory reference collection provides type specimens of larval fish that are used internally, mainly to train staff in ichthyoplankton taxonomy at SWFSC, but are also used to train students at SIO. The cephalopods in the collection have been used to train a fisheries consultant as well as SWFSC contractors.

The full historical time series of identified fish larvae and eggs are stored at SWFSC in “The vault”. This extensive collection is used by visiting experts with specialized interests, and is also used to provide specimens to universities and museums for specialized studies.

CalCOFI Management clients

Pacific Fisheries Management Council (PFMC)

The PFMC uses CalCOFI data as ancillary information to inform stock assessments of small pelagic species (Pacific sardine and Pacific mackerel), and to provide background environmental information relevant to monitored species (Market squid, northern anchovy, and jack mackerel) and protected species (krill). Graphical summaries are a key CalCOFI product that provide ancillary information for stock assessments. These data are now synthesized into presentations and reports specifically targeting the needs of the PFMC. For example, some of the CalCOFI graphical summaries prepared for the CCIEA are used in the PFMC forums. The State of the California Current publication is also used as background environmental material for PFMC meetings.

Surfaces, sections and time series of hydrographic data from CalCOFI cruises are presented to the Scientific Statistical Committee at PFMC meetings each year to describe the background environmental conditions underpinning estimates of biomass or relative abundance of species of interest. Time series of relevant species of fish larvae are presented to illustrate long-term and recent trends in abundance. Eggs of small pelagic species (sardine, anchovy and jack mackerel) collected by the Continuous Underway Fish Egg Sampler (CUFES) are overlaid on sea surface temperature (SST) maps from remote sensing imagery and used to illustrate the spatial distribution and abundance of spawning. CUFES/ SST maps are often presented as time series to show inter-annual variability. In summary, CalCOFI data are fundamental to providing the context for small pelagic species assessments.

As of March 2016, the PFMC has approved an amendment to Fishery Management Plans “prohibit[ing] the future development of fisheries” on a wide range of forage species until there is sufficient science to assess the impact of any directed fishery. These species include round herring, thread herring, mesopelagic fishes of several families, Pacific sand lance, Pacific saury, silversides, osmerid smelts, and pelagic squid of several families, excluding Humboldt squid (see PFMC web pages). CalCOFI plankton samples collect the larvae of a very wide range of taxa, from benthic shore fishes to coastal pelagic fishes to mesopelagic fishes to pelagic and mesopelagic squids. These species have been enumerated consistently and accurately, meaning that time series of the new forage species of interest are already in place.

Marine sanctuaries

In 2001 the State of California implemented the closure of bottom fishing within two large areas within southern California termed the Cowcod Conservation Areas (CCAs). A key question for both state and federal fisheries managers is whether these sanctuaries have contributed to the recovery of overfished rockfishes. Rockfish larvae collected by CalCOFI within and around the CCAs between 1998 and the present were recently genetically-identified to provide a time-series of rockfish spawning. Resultant data will help inform policies regarding these marine sanctuaries.

CalCOFI products

Data

CalCOFI provides a range of data products for long time series, including:

Extensive QA/QC datasets served on the web using the ERDDAP interface. This includes the full suite of all ichthyoplankton species abundance identified from oblique, vertical and surface plankton samples. The Continuous Underway Fish Egg Sampler data are also all served through ERDDAP. All SIO discrete-depth hydrographic data from Rosette CTD profiles are served on the same system. Details can be found on the NOAA ERDDAP home page.

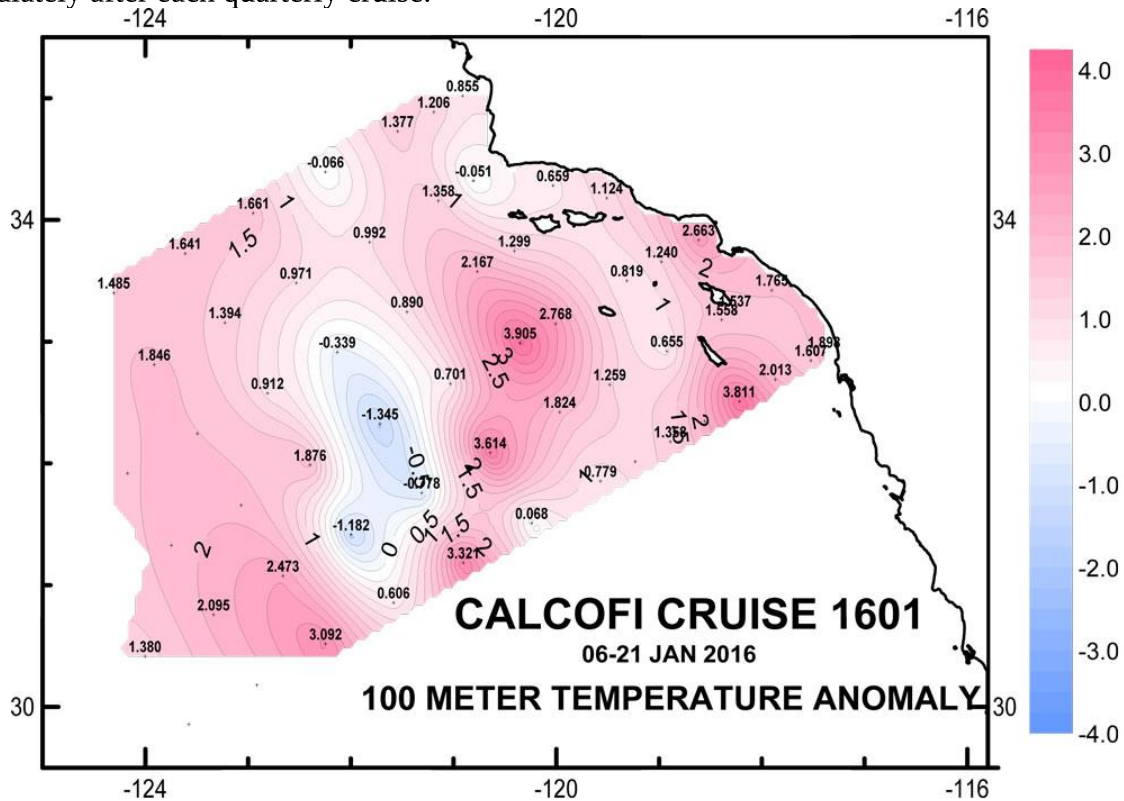
Temperature time series extracted from CalCOFI stations that are used in the harvest control guideline for the sardine assessment are tabulated and served on the SWFSC CalCOFI web pages. These data are updated annually.

Customized data extractions are provided in special cases where researchers request data that may be available but has not yet been posted to the web.

Syntheses

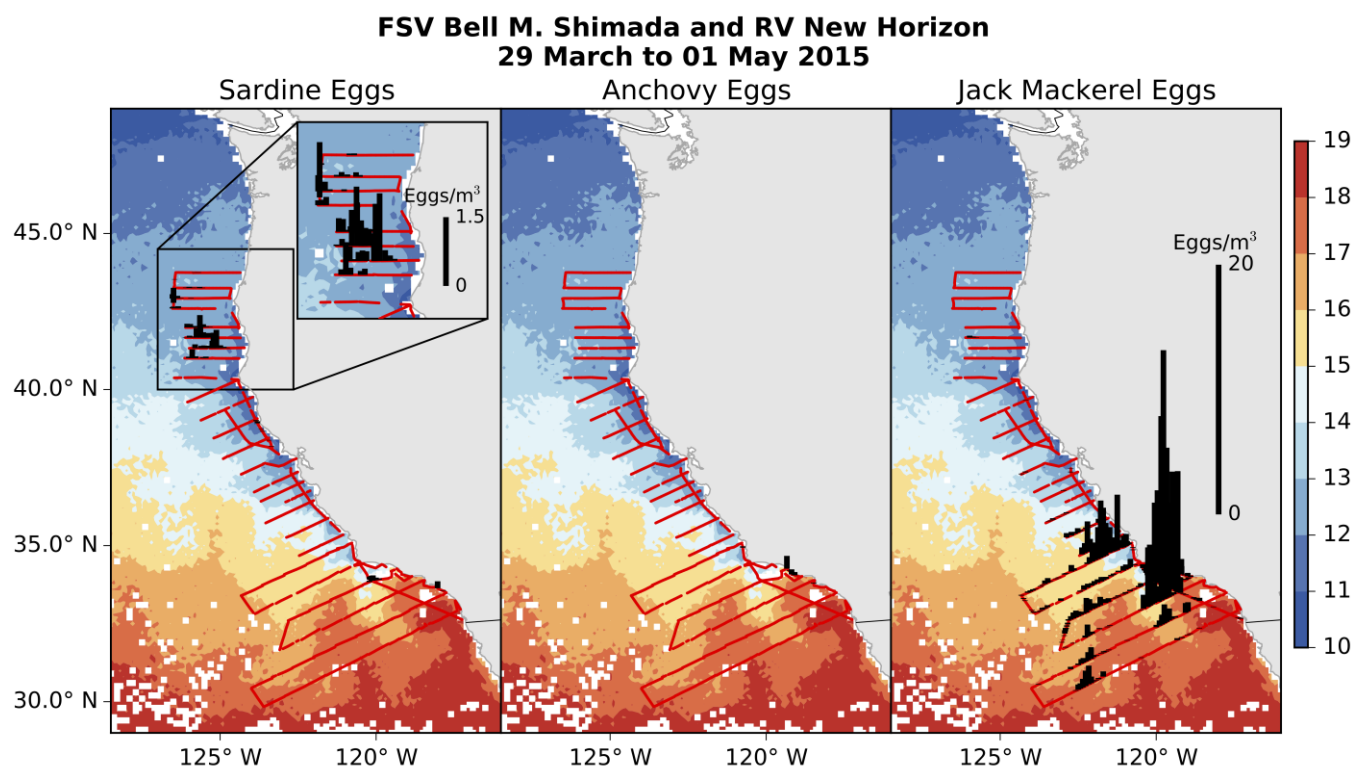
CalCOFI continues to provide a range of web-based products, reports, synthesized time series, analyses of current conditions, and a journal.

Preliminary surfaces of oceanographic variables are published on the SIO CalCOFI web pages immediately after each quarterly cruise.

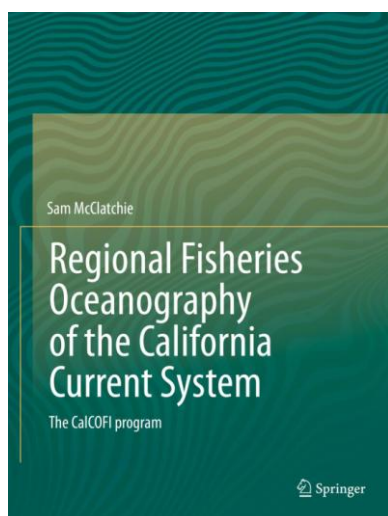


Egg abundance maps combining CUFES and SST are posted on the SWFSC CalCOFI web pages after spring cruises.

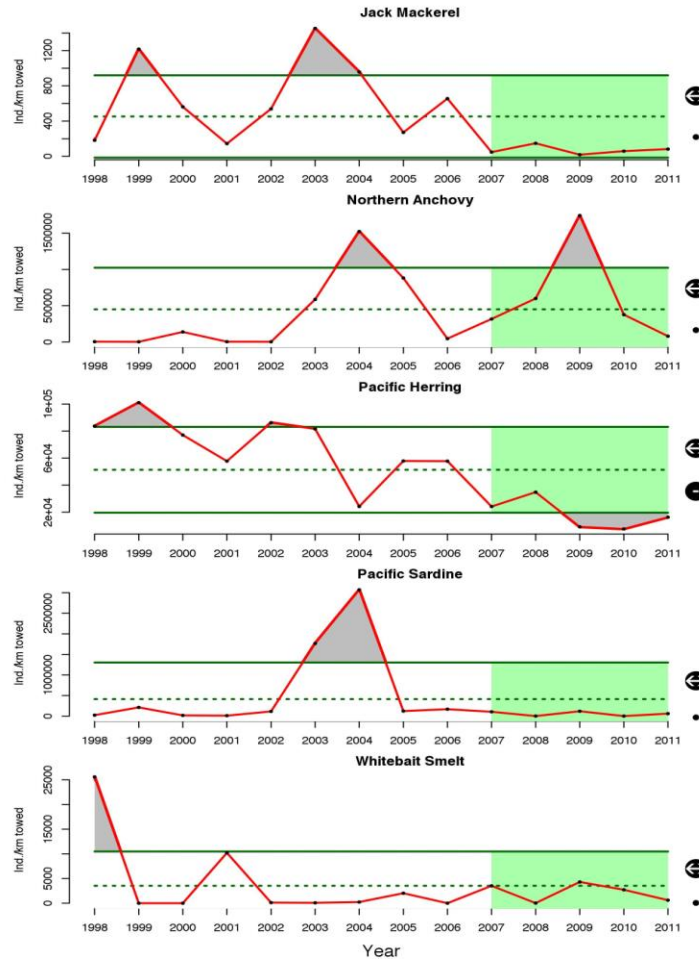
Each year, a peer-reviewed paper on the State of the California Current is published in the CalCOFI



Reports journal (e.g. Leasing et al. 2015), and the results are presented as a lead paper for the annual CalCOFI Conference. Many peer reviewed research publications are summarized in the CalCOFI book (McClatchie 2014), including over 600 papers in fisheries oceanography, and there are many others focused on biological oceanography including mammals, sea birds. CalCOFI Reports is an open access on-line peer-reviewed journal publishing results related to the CalCOFI program.



Time series are provided to the California Current Integrated Ecosystem Assessment (CCIEA)



Reference collections

The SWFSC ichthyoplankton laboratory, which fall under the umbrella of CalCOFI, continues to maintain and expand its reference collections. These include:

- the ichthyoplankton reference collection at SWFSC
- the full historical ichthyoplankton time series collection at SWFSC

CalCOFI staff process all bongo net samples for ichthyoplankton and displacement volume, and the samples themselves are archived at the invertebrate collection at SIO.

New methods

The SWFSC ichthyoplankton laboratory is applying new genetic and stable isotope methods to the CalCOFI ichthyoplankton samples, including:

- genetic ID of individual rockfish larva
- genetic ID of all fish species in a plankton sample through bulk tissue extraction and metabarcoding
- genetic ID of environmental DNA (i.e., DNA within water samples)

- stable isotope and compound specific isotopic analysis on amino acids to understand the composition of larval fish diets

Sea-going

Ship operations which falls under CalCOFI provides a sea-going team of 3 FTEs and one contractor (soon to be increased by filling two retired FTE positions in ship ops.). These staff spend up to 110 days per year at sea including cruises with stock assessment goals beyond the goals of the CalCOFI program. In addition, other members of the larger CalCOFI group (comprised of Fisheries oceanography, Ichthyoplankton and Ship Operations) take part in cruises, affecting availability of CalCOFI staff for tasks ashore.

CalCOFI staff contribute the largest number of staff to SWFSC FRD cruises, generally sending 5 to 7 staff on cruises that use trawling such as the spring CPS (approx. 30 days) and the summer SaKe cruises (approx. 80 days), and sending 2 to 4 staff on quarterly CalCOFI cruises (17-25 days each), in addition to participation in test cruises in recent years as new ships came online. This heavy cruise load has ramifications throughout the CalCOFI program, in terms of staff health and morale, processing of displacement volumes, sorting and identification of ichthyoplankton samples, and the timely delivery of data to the community through the web interfaces. In the last 10 years, cruise days utilizing CalCOFI staff have doubled, while the number of CalCOFI staff has declined, leading to an imbalance of resources, backlogs in sample processing, delays in delivery of data, and exhaustion of staff. Restoring the imbalance of resources and demands would ensure that CalCOFI can continue to deliver its products to our clients in an efficient and timely manner.

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